AENG 411: Aerospace Laboratory

Performance Characteristics of a Single Stage Axial Flow Air Compressor

by

Group No. 2

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# **Introduction**

A torsional pendulum consists of a long, stiff shaft fixed that is fixed at one end on attached to a large disk on the other. When said disk is rotated by a small angle and then released, the shaft will begin to rotate in a periodic fashion, the amplitude and frequency of which are highly reliant upon the moment of inertia and weight of the disk, as described in Equations (1-2), where *D*, *t*, *G*, *l*, and *ρ* are the respective diameter, thickness, shaft shear modulus, length, and density of the disc.

(1,2)

Based on these parameters, the equation of motion associated with the rotation of the shaft can be described by Equation (3), where *kr* is the rotational spring constant of the shaft, as described in Equation (4).

(3,4)

Based on these equations, the natural frequency and normal frequency can be described by Equations (5-6). Each of these correspond to the undamped frequency of oscillation of the shaft, so if one wants to find the damped frequency of oscillation, Equation (7) can be used, where the damping ratio, *ς*, is defined by Equation (8), where the logarithmic decrement, *δ*, is defined by Equation (9). The u values listed in Equation (9) correspond to amplitudes of oscillation at two separate points (i and i+j). Experimentally, these points can be considered at amplitudes of 90⁰ and 45⁰ respectively.

(5-9)

With all of these values in mind, the behavior of the shaft, disk system when disturbed from equilibrium can be properly predicted and assessed.

# Design of Test

#### 2.1. Objective

The goal of this experiment is to compare the measured natural frequency to the theoretical natural frequency.

#### 2.2. Test Apparatus and Function

The measurement tools and apparatus that were necessary to run this experiment are listed below:

* Steel and Aluminum Torsional Pendulums
* Test Stand
* Strain Gauge
* Strain Indicator
* DAQ

# Computer with LabView Procedure

1. A quarter bridge connection was made between the strain gauge and the strain indicator.
2. The indicator was zeroed and the gauge factor was set to 2.
3. One of the pendulums was placed in the clamp and the clamp was tightened.
4. The dimensions of the pendulum were measured.
5. The disc was rotated and released.
6. The natural frequency, damping ratio, and damped frequency were recorded.
7. The disc was rotated for a total of six trials.
8. Repeated steps 4-7 for a different shaft length (Note: the second length for the steel rod was not run, as the strain indicator for it broke between tests)
9. Repeated steps 4-8 for the other material.

# Results

For this experiment, the length and diameter of each rod, as well as the thickness and diameter of the plate attached to said rod, used during testing were recorded. Also recorded were the material properties of each rod-plate configuration, such as their density, weight, shear modulus, and moment of inertia. All of this information is listed in Table 4-1 and 4-2.

**Table 4-1. Rod/Disk Dimensions for Each Trial Run**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trial Type/Number** | **Rod Length (in)** | **Rod Diameter (in)** | **Plate Thickness (in)** | **Plate Diameter (in)** |
| Steel 1 | 43.75 | 0.13 | 0.50 | 5.80 |
| Aluminum 1 | 38.81 | 0.13 | 0.50 | 6.00 |
| Aluminum 2 | 43.88 |

**Table 4-2. Rod/Disk Material Properties**

|  |  |  |
| --- | --- | --- |
| **Property** | **Steel** | **Aluminum** |
| Density (slugs/in3) | 0.28 | 0.10 |
| Plate Weight (lb) | 3.78 | 1.39 |
| Shear Modulus (lb/in2) | 11600000 | 3800000 |
| Moment of Inertia (in4) | 0.00000137 | 0.00000164 |

Thus, it is possible to calculate the shear modulus of the shaft based solely on the weight of the plate and the moment of inertia associated with it

For after completing all 4 trial runs associated with each length configuration, the natural frequency, damping frequency, and damping ratio data for each case was recorded, as shown in Table 4-3. This data will later be compared to the theoretical quantities associated with each particular configuration, as discussed in the next section.

**Table 4-3. Frequency and Damping Ratio Data for Each Configuration**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trial Type/Number** | | **Natural Frequency (Hz)** | **Damping Frequency (Hz)** | **Damping Ratio** |
| Steel 1 | 1 | 11.781 | 17.781 | 0.00213941 |
| 2 | 11.786 | 11.786 | 0.001977642 |
| 3 | 11.7812 | 11.7811 | 0.002216811 |
| 4 | 11.7813 | 11.7813 | 0.002055716 |
| Aluminum 1 | 1 | 11.9473 | 11.9473 | 0.00063299 |
| 2 | 11.9557 | 11.9557 | 0.000164483 |
| 3 | 11.9572 | 11.9572 | 0.000307668 |
| 4 | 11.9543 | 11.9543 | 0.000620185 |
| Aluminum 2 | 1 | 11.2562 | 11.2562 | 0.00054268 |
| 2 | 11.2657 | 11.2657 | 0.000238577 |
| 3 | 11.2633 | 11.2633 | 0.000449644 |
| 4 | 11.2617 | 11.2617 | 0.000397172 |

# Discussion of Results

Only four trials instead of the planned eight for the first steel pendulum length were obtained and the data that was recorded was suspect. This is attributed to equipment failure, specifically the strain gauge on the pendulum shaft. Because the aluminum pendulum had a separate strain gauge, the data for the aluminum trials is not suspect. An example of the data plot for the first trial for the first length of aluminum is shown in Figure 6-1.

**Figure 6-1. Collected Rotational Displacement Data over Time for First Trial of First Aluminum Configuration**

The 90% confident mean population values of the frequencies and damping ratios listed in Table 4-3 were found using the “Student T-Distribution Method” described at the end of the Aerolab Structures Lab Manual. For each length and material, the number of sample points (v) was four. α was found using the equation:

(10)

From these values, Table A.4 in the Aerolab Structures Lab Manual was used to find the value of tα/2 = 1.533.

After this, the below equation was used to calculate the range of 90% confident mean population values for the frequencies.

(11)

The natural frequencies for the theoretical and experimental Aluminum lengths appear to be very similar, though the values for steel appear to be significantly different.

In order to find the logarithmic decrement, it was necessary to find *umi* , *um(i+1)* , and *j*. The lab manual recommended using the starting and ending amplitudes for *umi* , *um(i+1)*  and the number of cycles between 90° > φ > 45°. However, this range of times was not recorded during the experiment. Instead, the starting amplitude, ending amplitude, and total number of cycles for the 60 second observation period were used. The logarithmic decrement was calculated using the equation:

The damping ratio, ζ, was calculated using the equation:

The results of this calculation can be found in Appendix X, Table 5. The theoretical damping ratios were all greater than the corresponding observed values (Appendix X, Table 1) by a significant margin.

The damping ratio was then used to calculate the damped frequency using the equation:

The results of this calculation can be found in Appendix X, Table 5. Similar to the results of the natural frequency calculations, the damped frequencies for both aluminum lengths appear to match closely to the experimental values, with a percent difference of 0.795% for the first length and 0.712% for the second. However, the experimental and theoretical values for the steel data contrast sharply, with a percent difference greater than 19%. These percent differences can be found in Appendix X, Table 6, for reference.

# Conclusion

In this experiment measurements were taken to determine the performance of an axial compressor. Labview software was used to obtain readings for three different rotational speeds of the compressor (800, 1200, and 1600 rpms) at back plate locations of one, two, and three inches. The dynamometer readings that were obtained were used to determine power, pressure, and flow coefficients. In addition, Reynolds numbers were obtained. Plots were made of Reynolds number vs each of the coefficients. Increases in Reynolds numbers saw increases in the pressure coefficients and in the flow coefficients at each of the three distances. For the two and three inch back plate locations, the power coefficient tended to decrease slightly with increase in Reynolds number. (The back plate distance of one inch was felt to have spurious results due to inaccuracies in measurements, when the power coefficient was measured.)

Error analysis was done using percent uncertainty for five variables in the lab – rpm, scale reading, temperature, pressure, and diameter. These were then incorporated into the error analysis to obtain a +/- reading for each of the coefficients. The uncertainty of each of the coefficients ranged from a factor of 10 ^-2 to 10 ^-4. The Reynolds number had an uncertainty value of +/- 6505. However, this should be kept in context that Reynolds numbers are of the 10^5 range.

The objective of the experiment was meant in that it showed the performance characteristics of the single stage axial flow air compressor were quite good with the efficiency of the axial compressor having an uncertainty value of +/- 0 .000090.